"Light, Waves and Interference" - A Teacher's Workshop

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Build Your Own Interferometer

Background

On a clear dark night you might step outside and look at the sky. If you are lucky to live in an area where the sky is dark enough, you will see the sky covered in stars. You might also have looked through a small telescope to observe different stars. Many people are surprised to notice that all stars just appear to be dots on the sky and none of them appear as disks like our own Sun does. This is due to the limited resolution our eye and small telescopes can provide. Or in other words, the stars are just too far away to see the difference in their sizes.

Below we will show how the wave nature of light limits the resolution of a conventional telescope by representing the telescope by a single opening (representing the diameter of the telescope) so small that the resulting interference patter is visible to the unaided eye. In a second step, we will demonstrate how the light from two openings (or telescopes) can be combined so that the two act as an interferometer. While the resolution of a conventional telescope is only limited by the diameter of the largest opening, the resolution of an interferometer is limited by the separation of the two opening and is independent from the diameter of each of the two small openings.

We will demonstrate first the effect using a small light source and a prefabricated card ("Pocket Interferometer") and will then show you how you can build your own pocket interferometers.

Materials

- 3X3 piece of aluminum foil
- 2X2 piece of pressed cardboard
- New push pins
- Single point light source (e.g. Mag Light, Flash Light with the reflector removed)

Procedure

During the workshop we will hand out white cards with the headline "Space Interferometry Mission". They are made from white cardboard with a piece of black film glued to the back. To use these cards you will need a small light source. We are providing "Mag Lights", small flash lights where you can remove the reflector to expose the bulb.

Remove the reflector from the body of the flash light. Make sure that it is turned on. Hold the light at arms length. You might also put the light on the table in front of you and look at it from a distance of at least 3 feet. Close one eye and hold the white card close to your other eye. First, try to look through the left black circle at the flashlight. After a little adjustment, you should see slightly distorted concentric rings around the light source. If you move over to the right opening, labeled "interferometer", and look again at the light, you should see a different pattern. You will still see concentric rings. However, if you look more closely, you will see narrow bands of light and dark areas on top of the concentric rings.

Explanation

Sometimes I get asked whether the patter you see through the cards is printed onto the film. The answer is no. To see for yourself, hold the card at a comfortable distance and look closely at the two black areas while holding the card in front of a bright background like a white sheet of paper. If you look carefully, you will see that there is one tiny hole close to the center of the left black area. Near the center of the right black disk you will find two tiny holes close to each other.

You see concentric rings through the single hole because light waves entering on opposite side of the opening interfere with each other. A dark ring is produced, where the crests of the waves coincide with the troughs of waves from the other side. The two waves then cancel each other and create an area of darkness. A bright ring results where the crests of the waves overlap with each other. Waves from opposite sides of the opening in this area therefore amplifying each other and produce a bright ring. The patterns are concentric rings because the hole is round. If you were to choose a long slit instead of a single hole, you would see vertical bands instead.

Now to the second opening with two tiny holed next to each other. You see the faint concentric rings because each of the holes is round and will produce an interference patter as described above. In addition, you can now also observe vertical bands that stand at right angle along the connecting line of the two openings. These lines originate the same way the rings originate, but this time it is light that enters through the left opening that interferes with light that enters through the right opening. Patters of dark and light bands result at equal distances from the left and the right band. That is why you see lines.
The distance between the dark and light bands depends only on the separation of the two small holes and the wavelength of the light you are using. The further the two openings are apart, the finer the lines will become. You are holding in fact a very simple interferometer in your hand. Before we go into more details we will explain how you can create your own interferometer, if you don't have one of our handy cards, or if you want to make additional copies.

Build your own Interferometer

Place a sheet of paper or thin cardboard on a flat hard surface. Put a small piece of aluminum foil on top of the cardboard and straighten out any wrinkles by gently stroking the aluminum foil. Try to make the piece as flat as possible. Now take a new, sharp push pin (push pins are easier and safer to handle than needles) and poke a small hole through the aluminum foil. Make the hole close to the center the piece of foil that you are using. Do not push the pin all the way through but try to use only the very tip of the pin. You might have to try a few times to get the right size.

To check your result hold the piece of aluminum foil close to your eye and look through the tiny hole you just created at the flashlight as described above with the cardboard card. If the opening has the right size, you will see rings around the light. If you made the hole to big, you will simply see the flashlight. Experiment with different sized holes and notice how the separation of the rings changes as you change the diameter of the holes.

When you know how to get small enough holes to see the rings clearly, try putting a second hole next to the first hole. Try to place the second hole as close as you can to the first hole. Make sure that you are really creating two tiny holes. When you now hold the piece of foil up to the light you will see vertical bands in addition to the concentric rings. Experiment with different distances between the two holes and notice how the lines get finer as you increase the separation between the two holes.

Extension

Resolution Depends on Color. You can use either one of the interferometry cards or one of the pieces of aluminum foil to do more exploring. When you use the aluminum foil, make sure you have a sample with two holes that allows you to see vertical bands clearly.

When you look at lights of different colors you should notice that the separation of the dark and light bands changes for different colors. The bands will be further apart when you look at a deep red light. If you compare what you see with red light with a bright green or blue light, you will notice that the bands are closer to each other as you go from red to green and blue.

This illustrates that the resolution of an optical instrument does not only depend on the physical size of the instrument, in this case the separation of the two openings, but also on the wavelength of the light that you are interested in.

Measure the Size of a Light Source. This time use your small flashlight as a light source. Hold the aluminum foil or the interferometer close to your eye and bring the flashlight close to the card, probably about four inches from the card. Now turn the flashlight in your hand around the long axis of its body (this might read more complicated than it is). As you turn the flashlight and adjust the distance between the card and the flashlight you will notice how the contrast between the dark and the light bands changes. At some time the bands might disappear all together.

Now turn the flashlight off and look closely at the bulb. You should notice that the small filament in the bulb that is heated by the current from the battery is a small horizontal piece of wire. As you turn the flashlight you will alternate between seeing the full width of the filament and looking along the length of the filament By turning the flashlight you are effectively changing the size of your light source.

By creating the interferometer with a set separation of the two opening, you have also preset the resolution of the interferometer. Each time you are looking at a light source that is larger than the resolution of the interferometer you are using, the interference bands will disappear. By using cards with different separations of the openings, you can in turn measure the diameter of a light source. This is in fact the same method Albert Michelson used in 1919 to measure for the first time the diameter of the star Betelgeuse in the constellation Orion.

Standards

A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity.

Science Standards:

Primary (K-3) Science Standard 12 - *Understands motion and the principles that explain it.*
a) Knows that light travels in a straight line until it strikes an object.
b) Knows that things move in many different ways (e.g., straight line, zigzag, vibration, circular motion).

Middle School (6-8) Science Standard 12 - *Understands motion and the principles that explain it.*
Knows ways in which light interacts with matter (e.g., transmission, including refraction; absorption; scattering, including reflection).

For more background on interferometry and its application in astronomy also see the Web page of the Space Interferometry Mission http://sim.jpl.nasa.gov